CHAPTER 9

MAINTENANCE

9-1. Objective

In most common electrical systems, two types of maintenance are normally recommended, routine and preventive. Routine maintenance is that which is required to ensure continued operation of the system and is usually that which is recommended by the equipment manufacturer. Preventive maintenance carries the routine maintenance one step further by performing actions, such as replacing components that may be nearing their end of life, that prevent failures of systems that would cause unwanted outages. Breakdown maintenance is the minimum level performed by all organizations and consists of those actions conducted after a failure to restore equipment or systems to an operational condition. The main objective of a preventive maintenance program is to reduce the number of avoidable breakdowns. A well-planned and efficient preventive maintenance program is expensive; it requires shop facilities, skilled labor, keeping records, and stocking of replacement parts. However, the cost of downtime may amount to ten or more times the actual cost of repair, and possibly compromised security and the problem cascading into related systems. Therefore, maintenance must be scheduled into the operation of any automated data processing (ADP) system that will be processing hard to replace or sensitive information.

a. When preparing maintenance schedules, it must be recognized that too frequent inspections are a waste of money and that insufficient inspections place vital equipment in jeopardy. The frequency of inspection should depend on the equipment's contribution to profitable production, its duty cycle, age, overload, and other pertinent factors. The manufacturer of electrical equipment will recommend an inspection cycle that may be modified later by experience. A good maintenance program provides for scheduling equipment out of service for routine overhauls during periods of least usage, rather than risk a breakdown at an inopportune time. Thus maintenance can be done at a time convenient to the production or operating schedule. Some companies find it convenient to close down completely during the vacation periods to provide time for planned overhauls.

b. All equipment should be classified as to its role in the manufacturing or operating process. Machinery and control equipment that could halt operations if a breakdown occurred should be classified as vital equipment and should be provided with a very comprehensive preventive maintenance program. Other equipment, such as room air conditioners, electric fans, drinking-water coolers, etc., should be classified as non-vital equipment. A breakdown of non-vital equipment will have little or no adverse affect on the processing of information or safety, etc., and a simplified maintenance program may be used. The decision to provide the same degree of maintenance for non-vital and vital equipment must be made with as much consideration as was given to the selection of the equipment itself. The cost of such programs should be considered as part of the unit cost of operation or production. The essentials of an effective preventive maintenance program include record taking and interpretation, acquisition of adequate replacement parts, skilled labor to carry out the program, and cooperative management.

c. It must be recognized that the deterioration of electrical equipment is normal, and this process begins as soon as the equipment is installed. If deterioration is not checked, it can cause electrical failures and malfunctions. Load changes or circuit alterations may be made without overall design coordination, which can result in improper settings of protective devices or wrong trip units installed in the circuits. With an electrical preventive maintenance and testing program, potential hazards that can cause failure of equipment or interruption of electrical service can be discovered and corrected. Also, the program will

minimize the hazards to life and equipment that can result from failure of equipment when it is not properly maintained.

d. The systems within an ADP facility may interface with one another, such as main electrical power; emergency power; dedicated "clean" power; utility power; fire and security systems hydraulic; pneumatic; heating, ventilation, and air-conditioning (HVAC); and other mechanical systems. Therefore, it is important to know how these interfaces work and how they can be coordinated in the maintenance program. Related systems within a facility cannot be overlooked. The air-conditioning and heating system that maintains temperature and humidity levels in an ADP center can result in ADP equipment failures if this equipment fails. HVAC systems produce a quality work atmosphere for ADP personnel but more importantly the HVAC systems produce controlled conditions that are essential to reliable ADP operation.

9-2. Maintenance program

The main objective of planning preventive maintenance in an ADP system is to provide quality power at a reasonable and acceptable cost.

a. This objective can only be reached by implementing a well-planned maintenance program that will:

(1) Improve overall plant and equipment productivity through continuous operation and production by reducing downtime.

(2) Minimize maintenance expenditures through budgeting for planned versus replacement cost by collecting data on equipment and production downtime.

(3) Establish maintenance priorities by analyzing equipment and production priorities.

(4) Stock replacement parts for high priority apparatus.

(5) Implement the best maintenance techniques and test equipment.

b. The era of growing old with equipment is over. Today, it is impossible for untrained maintenance personnel to keep pace with the continuous changes in electrical equipment being produced through advanced technology. Service and maintenance requirements for electronic and solid-state circuitry require a high level of specialized training and skill. The individual who is not given the opportunity, or is unwilling to update the educational requirements necessary for the maintenance of modern equipment, is faced with the possibility of being phased out along with the obsolete equipment being replaced. This is a reality facing anyone who is expected to service and maintain sophisticated and more complex apparatus.

c. Plans for a maintenance program should be one of the first considerations when a new plant is constructed, additions made, or more modern equipment purchases are installed. At this time, conditions are ideal for one or more of the maintenance personnel to inspect the normally inaccessible parts of equipment and to ask questions of the installing contractor or the manufacturer's representative in order to learn as much as possible about the maintenance requirements for new equipment coming under their jurisdiction.

d. Total familiarity with the electrical equipment is a necessary prerequisite for any maintenance program to be successful, and an extremely valuable asset to rely on if it becomes necessary to correct or repair any operating problems within the electrical equipment.

e. The main parts of the maintenance program can be classified into maintenance management considerations, technical requirements, and those items that should be included in the electrical maintenance and test program.

(1) The design of any maintenance program must meet the ultimate goals of management. Maintenance is like an insurance policy: it has no direct payback, yet it is a cost that adds to the cost of the final product. However, one must hasten to say that it has inherent payback. It is generally observed that management resists the investment in a maintenance program even though they realize the need for good maintenance. In view of this, it is up to electrical personnel to show management how a properly planned electrical maintenance and testing program is justifiable.

(2) The planning of the programs should then include the advantages of well-planned maintenance along with cost data for lost production due to equipment failure versus cost of budgeted preventive maintenance. Any maintenance program should prove that it is cost effective and minimizes equipment failure. The planning of the program should include considerations for proper test equipment, tools, and trained personnel to carry out maintenance routines. Also, consideration should be given to record-keeping systems, which can range from fully computerized to manual file systems. To set up an electrical preventive maintenance and test program, the following steps may be undertaken.

(a) Determine the factors that will form the basis of the maintenance program, such as the necessity for continuous production, and management policy on budgeting for planned maintenance versus replacement of equipment.

(b) Survey and consolidate data on equipment breakdowns and cost of lost production. Make an analysis of the cost data to convince management of the benefits of planned maintenance.

(c) Establish electrical maintenance priorities. These consist of on-line production sequence, determining the most important to least important equipment, weighing the reliability of the equipment, and other factors.

(d) Establish the best maintenance techniques. This involves selecting the best maintenance method and personnel for the various types of equipment and systems.

(e) Schedule and implement the program. Monitor its benefits and costs. Analyze program functions periodically for improvement of the program.

f. After the program has been set up, it is essential that it consist of five elements that will prove it to be a success: responsibilities, inspection, scheduling, work orders, and record-keeping.

(1) The responsibilities of the maintenance organization should be clearly defined by organization charts with functional work statements for each unit. The functional work statements must be established by management as a matter of policy. Every other department must be informed of the responsibilities assigned to maintenance organizations. The effectiveness of the maintenance departments will depend upon how well they are organized and how well personnel are utilized.

(2) Inspection is the key to the success of any maintenance program. Sufficient time should be allocated for inspection to verify the condition of new and installed equipment. The purpose of inspection is to provide advance warning as to the condition of the equipment under investigation. When inspection is performed on definite cycles by qualified people, impending deterioration can be detected in advance so that repair or replacement can be made before failure of the equipment occurs.

(3) To perform maintenance, a definite schedule of work to be performed must be established. Maintenance schedules must be based upon minimum downtime for the various operating segments. The schedule for inspection, routine maintenance, and other work may vary for different equipment and will depend upon many factors. These factors can be age of equipment, frequency of service, hours of operation, environmental conditions, damage due to abuse, and safety requirements. Frequency of scheduling of the tasks should be adjusted as data on various equipment are recorded and analyzed to provide a balance between cost of maintenance and replacement cost of the equipment.

(4) Work orders are job requests that need action for completion. Work orders can be established for all inspection service and other work on equipment in terms of routines. Any of these routines should include information on when such work is to be performed, where it is to be performed, and exactly what has to be done. These routines can be generated by a computer-based maintenance system. The routines should include all the pertinent information concerning the equipment.

(5) The success of a planned maintenance program depends upon the impetus given by top management and the interest of the maintenance personnel in the program. To have an effective program, it is imperative that maintenance and test inventory data on all equipment should be complete and readily available throughout the service life of the equipment. To that end, record-keeping is very important. All forms and reports should be organized to provide ready accessibility to data when needed and to flag down problem areas. Such data may also be used over the years to analyze trends for equipment deterioration. If data is not recorded and maintained properly, the whole purpose of planned maintenance is lost.

9-3. Maintenance data file

The maintenance data file of the ADP system will include the information relating to the hardware within a defined system, a list of maintenance personnel qualified to support the equipment, training records with the level of skills achieved, current data on manufacturers representatives, renewal parts vendors, consultants with a special field of expertise that is not available in house, and the service organizations on contract to maintain equipment.

a. The most important phase of a preventive maintenance program is the recording and interpretation of data pertinent to each piece of equipment. One method of data file record-keeping will use two or more file cards for each piece of equipment. The equipment record card should include the motor nameplate data, location in the plant, purchase price and installation cost, application, and the manufacturer's replacement part number for each replaceable part. The history card should include the date of each periodic test, the test data, the type of repairs, the manhours, the cost of each repair, and the initials of the workman in charge of the job. This data can be transferred to a computer database for which there are many software packages available.

b. The data file is the only way to preserve the integrity of data accumulated over the life of the equipment. It indicates when maintenance costs are beginning to exceed the normally anticipated expense so plans can be initiated to purchase new or higher rated apparatus.

c. Since maintenance is a continuous activity, it is extremely important that historical records be kept and updated on all apparatus. The place for this type of information is in the maintenance department file, not in a hip pocket, notebook, or central engineering office where it cannot be reviewed regularly.

d. The record card should indicate the maintenance task performed, why it was necessary, and whether it was a routine breakdown or an emergency repair resulting from some extraneous cause.

Additional information should include how long it takes to perform the maintenance work on the equipment, and what particular maintenance tasks must be performed regularly. An immediate update of the record card should follow each maintenance period, and the report should be comprehensive enough to assist anyone in determining whether all required maintenance was performed. This also holds true for any type of maintenance periods, such as emergency repairs.

e. When adding circuits to existing equipment or making any changes in wiring different from the original drawings, it is essential that these changes be noted on the record cards. If wiring changes are not recorded when they have been made, they are sure to be forgotten and more time will be required to correct an otherwise routine maintenance task. More importantly, however, new circuits may be added and connected to points of greater power, causing them to remain energized when the circuit breaker is opened. Someone may be seriously injured because it is assumed that all connected circuits have been de-energized when power has been turned off at the source. Never add a circuit without first establishing its effect on the performance capabilities of the system or without immediately changing circuit drawings to show the source of power and the added load requirements. Such action can result in feeder circuits that are dangerously overloaded or a system imbalance. This can cause other connected loads to fluctuate or even be interrupted due to voltage drop when some high current equipment load is started or stopped in another area of the plant.

f. Each time a piece of equipment is serviced, a record should be made indicating the date, work performed, changes made, and probable cause of any problems other than routine servicing. A "fat file" may indicate a misapplication or misuse. It may also indicate that load conditions may have changed, requiring replacement with equipment of greater capacity and longer life.

9-4. Personnel qualifications

Maintenance personnel should be selected on the basis of qualifications for the job. Assignments should not be made on a hit-or-miss basis to those who happen to be idle at the moment. Equipment may be ruined by overzealous, inexperienced personnel. The maintenance department must not be a catchall for personnel who could not adjust elsewhere. The complexity of control systems in automatic and semi-automatic facilities requires well-educated and skilled personnel in the maintenance department. Very often, because of the newness and complexity of the maintenance requirements, special training may be required. A skilled maintenance force must be kept abreast of the latest techniques and developments in the field. This may be done by visiting plant maintenance shows, subscribing to appropriate periodicals, and attending specialized classes, panel discussions, and lectures.

a. A file of equipment manufacturers' bulletins and instructions should be available to all maintenance personnel. Only modern testing equipment, good tools, and the latest methods should be used. Whenever possible, maintenance standards and testing procedures recommended by the Institute of Electrical and Electronics Engineers (IEEE), American National Standards Institute (ANSI), National Electrical Manufacturers Association (NEMA), InterNational Electrical Testing Association (NETA) and the National Fire Protection Association (NFPA) should be used. A good preventive maintenance program represents insurance against avoidable outages that can completely de-stabilize an ADP facility.

b. Additional personnel who possess a greater degree of technical training and specialized skills should be added to the work force if necessary. However, when the plant inventory has only one or two pieces of specialized equipment, the maintenance department should call in a manufacturer's field service representative when a problem develops, which is usually less costly in the long run.

c. Inexperienced personnel attempting to repair or service any type of apparatus can spend hours trying to locate trouble, and the repair could possibly cost more than the replacement of the equipment. In

the process the employee may disturb or alter adjustments which only a factory-trained service representative can restore, and his actions may affect the reliability of the equipment or even the entire system. There is also the possibility of further damaging the apparatus and incurring additional expense because of experimenting or attempting to keep equipment operating when it should be repaired. By using a manufacturer's representative, maintenance personnel can acquire a considerable amount of knowledge if they are present when the representative is working on the equipment. After a few service calls, the maintenance man may know enough about the equipment to repair and maintain it himself in the future.

d. Certain guidelines should be adhered to when selecting outside assistance to contribute to a maintenance program. It is of course possible to contract out all and every level of responsibility associated with maintenance and testing.

(1) There are certain advantages when utilizing contractor help.

(a) The testing and maintenance firm can be a corporately independent testing organization which can function as an unbiased testing authority, professionally independent of the manufacturers' suppliers, and installers of equipment or systems evaluated by the testing firm.

(b) The testing and maintenance firm is regularly engaged in the testing of electrical equipment devices, installations, and systems, and will, therefore, maintain a degree of expertise that may be difficult for in-house personnel to achieve and maintain on a cost effective basis.

(c) The testing and maintenance firm can be required to utilize only full-time technicians who are regularly employed by the firm. Electrically unskilled employees are not permitted to perform testing or assistance of any kind. Electricians and/or linemen may assist, but may not perform testing and/or inspection services.

(d) The testing and maintenance firm can supply all test equipment that may be required for any level maintenance.

(e) Test equipment furnished by an outside firm can be required to be inspected and calibrated within established industry standards.

(2) Disadvantages to using contractor help include the following.

(a) There can be many disadvantages associated with the maintenance program of any sensitive electrical system or for that matter, any system. There is, however, one disadvantage that may far outweigh any advantage.

(b) The testing and maintenance firm is not sensitive to, neither can it be motivated to be sensitive to, the critical intrinsic needs of the client.

9-5. Dedicated maintenance equipment

The maintenance equipment that is necessary to support, maintain, troubleshoot, and service the ADP system is sensitive and sophisticated. A well organized maintenance department will own and maintain, or have ready access to all of the test equipment that shall be needed to support their mission.

a. The test equipment may be purchased and kept on site or it may be leased through an outside vendor. Test equipment may be furnished by a contracted maintenance agency. The manufacturers of the ADP system equipment being maintained should be consulted when selecting test equipment.

b. Maintenance and test equipment that is used to maintain other equipment must also be maintained and serviced on a regular basis to insure its reliability and accuracy. Test equipment should be maintained by a qualified firm and a calibration program should be established which maintains all applicable test instrumentation within rated accuracy. The accuracy shall be traceable to the National Bureau of Standards in an unbroken chain.

(1) Instruments shall be calibrated in accordance with the following frequency schedule.

(a) Field instruments – 6 months maximum

(b) Laboratory instruments – 12 months

(c) Leased specialty equipment – 12 months

(d) Dated calibration labels shall be visible on all test equipment

(2) Records must be kept up-to-date which show date and results of all instruments calibrated or tested.

(3) An up-to-date instrument calibration instruction and procedure will be maintained for each test instrument.

c. Personnel assigned to the use of this equipment must be thoroughly trained in its efficient and safe use.

9-6. Renewal parts

Renewal parts have always been and probably always will be a very temperamental subject with accountants and budget planners. Renewal parts contribute nothing to a system until they are needed. The maintenance manager should place the stocking and continuous maintenance of renewal parts high on the priority list to maintaining a reliable ADP system.

a. A carefully selected assortment of spare parts is essential to a good maintenance program and represents insurance against prolonged shutdowns. Even though repairs may not be made on the premises, keeping an adequate stock of spare parts will avoid delay in placing the machine back in service. Overstocking and understocking should be avoided. Overstocking results in excessive carrying costs as well as losses due to obsolescence when equipment is replaced. Understocking places the system in jeopardy if an outage occurs. Very often replacement parts for one machine may be used on many other units in the same area. In such instances it is unwise to stock spares for each unit alone, but to follow the manufacturer's recommendations concerning the minimum that is permissible for a group of equipment.

b. When making the decision to stock renewal parts, keep in mind the objectives of the maintenance program. If there is any uncertainty as to type and a variety of renewal parts to be stocked, the original equipment manufacturer should be consulted. The manufacturers should be provided with the critical nature of the system and the level of expertise of the personnel maintaining the system.

9-7. Continuous inspection program

The equipment within an electrical system is prone to failure for a myriad of reasons. These failures may occur for no apparent reason or the cause of failure may be poignantly apparent.

a. The failure of electrical equipment should be analyzed to assess reasons for its breakdown. Unless the cause is obvious, the equipment quality may be questioned. Reliability can be built into the equipment, but it requires upkeep to retain it. The tendency to ignore regular maintenance and testing generally prevails over regularly scheduled maintenance because regular maintenance may be considered unnecessary and too expensive. Therefore, the best designed and built equipment may break down through lack of attention. Every failure should be analyzed for its cause so that corrective measures can be implemented to prevent similar breakdowns.

b. A well-managed maintenance program will include an on-going and continuous inspection program to monitor equipment. The main objective of continuous inspection will be to avoid unscheduled outages and downtime. All equipment failures should also be reviewed and included in a continuous inspection program. The cause of equipment failure may be readily determined if analyzed soon after the failure occurs and other factors are available which may become lost if the analyzation process is delayed.

c. The importance of a continuous inspection program will be determined by the critical nature of the product of the ADP system. The inspection program may be limited to taking daily load readings or it may include sophisticated computer monitoring of load, heat, and vibration sensors to list only a few.

9-8. Maintenance schedule

The purpose of the maintenance schedule is to establish the condition of the equipment and determine what work will be required before its next scheduled maintenance. Usually, manufacturers' service manuals specify recommended frequency of maintenance and/or inspection. These time intervals are based upon standard operating conditions and environments. If these standard conditions change for the equipment, then the frequency should be modified accordingly. However, once the frequency of scheduled maintenance is established, this schedule should be adhered to for at least several maintenance cycles.

a. The schedule should be adjusted if the equipment begins to experience unexpected failures. The frequency can be reduced by as much as 50 percent. On the other hand, if the equipment does not require maintenance for more than two inspections, the period of frequency for that equipment can be increased by as much as 50 percent. Adjustment should be continued until the optimum interval is found. Generally, the test frequency can vary from 6 months to 3 years.

b. An efficient maintenance department will schedule in advance jobs that cannot be performed while a plant is operating. Time must be allotted to do a good job, or the quality of the maintenance program and the equipment will eventually be affected. However, sufficient time must be allowed to perform proper maintenance. If more work is scheduled than can be completed during a shutdown, the equipment will be returned to service with certain maintenance tasks not completed. The net result is that the job card will indicate that servicing was performed, but in actuality certain operations will be missed and not reported. This means that these operations will not be performed until the apparatus is scheduled for maintenance at another time.

c. If components appear to be wearing out faster or repairs are required more frequently than in the past, it could be that the equipment is now required to carry additional loads for prolonged periods of time, or a single shift is now operating around the clock. This will accelerate maintenance requirements

and alter the maintenance schedule. For instance, a reduction in the life expectancy of expendable items such as contacts can only come about due to a greater number of operations or under additional load requirements.

d. The following guidelines provide a means by which an effective maintenance program can be scheduled.

(1) Establish objectives for the maintenance department.

(2) Plan the maintenance program in advance.

(3) Train the employees in the necessary technical areas.

(4) Initiate a data file on each piece of equipment, and keep it updated.

(5) Perform all indicated maintenance according to the original schedule.

(6) Call in a manufacturer's representative when necessary and provide necessary lead time so that the representative can be on hand for the maintenance.

9-9. Maintenance tests

Preventive maintenance and testing will allow the prediction of impending failure of a particular piece of equipment so that plans can be made to replace it without catastrophic results. The information on testing can be obtained from several different standards, such as the Insulated Cable Engineering Association (ICEA), NFPA, IEEE, ANSI, NEMA, NETA, Insurance Company Manuals (ICM), and others depending on the equipment to be tested.

a. Field tests are conducted to see whether newly installed equipment has been damaged, to indicate whether any corrective maintenance or replacement is necessary on existing equipment, to indicate if the equipment can continue to perform its design functions safely and adequately, to chart the gradual deterioration of the equipment over its service life, and to check new equipment before energization. The types of tests are acceptance tests, routine maintenance tests, and special maintenance tests that are conducted for specific purposes.

(1) Acceptance tests are known as proof tests and are performed on new equipment, usually after installation and prior to energization. They are run to determine the following.

(a) Whether the equipment is in compliance with the specification.

(b) To establish a bench mark for future tests.

(c) To determine that the equipment has been installed without damage.

(d) To verify whether the equipment meets its design intent and limits.

(2) Maintenance tests are performed at regular intervals over the service life of the equipment. They are made concurrently with preventive maintenance. In the course of routine maintenance tests, it is very helpful to record the information as it is found on the equipment and to also record the condition in which the equipment is left. Therefore, these tests can be further subdivided into the following.

(a) As-found tests are performed on equipment on receipt or after it has been taken out of service for maintenance, but before any maintenance work is done.

(b) As-left tests are performed after maintenance has been performed and just before re-energization. They can indicate the degree of improvement in the equipment and serve as a bench mark for comparison for future tests.

(3) Special maintenance tests are performed on equipment that is known to be defective or has been subjected to adverse conditions that may affect its operating characteristics. An example might be the fault interruption by a circuit breaker, which requires inspection, maintenance, and tests before it can be put back into service.

b. The final technical function in developing a maintenance and test program involves establishment of instructions, procedures, and methods to ensure that the equipment and system components operate without failure. The maintenance department should have fully developed procedures and instructions for thoroughly servicing all equipment and components. In addition, the maintenance department should develop shutdown procedures, safeguards, interlocking of equipment, alarms, and methods of recording data and reporting unusual conditions to the proper authority. The maintenance records should be further utilized to evaluate results and as an indicator of possible modifications or changes in the maintenance program. In other words, the recorded information should be used as historical data and for feedback to modify the maintenance program.

9-10. Safety

Safe performance of maintenance is of prime importance when planning a preventive maintenance program.

a. All electrical wiring should conform to the recommendations of the National Board of Fire Underwriters as presented in the National Electrical Code (NEC). Machinery and other equipment should be installed with a view toward easy accessibility for maintenance. Joints and valves for water, steam, waste, and other liquid-carrying lines should not be located over electrical apparatus unless such equipment is drip-proof or splash-proof as required. Only approved safety solvents should be used for cleaning insulation, bearings, and other parts.

b. Switches and circuit breakers should always be closed completely and with a swift firm action. This will enable the quick operation of a fuse or breaker if a fault exists. Partially closing the switch or tickling the contacts “to see if everything is alright” is dangerous. The high-resistance path of a partially closed switch will cause severe burning and arcing at the contacts.

c. Before attempting repair work on electrical equipment, it must be disconnected from the power supply. The incoming lines to the apparatus must be tested with a voltmeter or voltage tester of the correct range for positive proof that the circuit is dead. All capacitors, connected to the apparatus must be discharged.

d. The following rules and guidelines should be adhered to when performing any maintenance or testing.

(1) All circuits and equipment are to be considered as energized until proven de-energized by testing with voltage detectors, and grounding cables are connected. The voltage detectors selected should be for the class of voltage supplied to the circuits and equipment to be serviced.

(2) Personnel assigned to on-site electrical service work should be supplied with at least two electrical voltage detectors. The voltage detectors provided shall be capable of safely detecting the voltage present in the circuits and/or equipment to be serviced. The assigned personnel shall be instructed in the correct operation of each detector before each on-site electrical job.

(3) Each electrical circuit and/or piece of equipment to be serviced should be tested by an assigned person with two detectors and then tested by one other person who has been trained in the correct operation of the voltage detectors. This testing shall be performed in the assigned person's presence to insure that the electrical circuit and/or equipment is de-energized.

(4) The voltage detectors should be checked for proper operation immediately prior to and immediately after testing the electrical circuits and/or equipment to be serviced. These checks should be made on a known source of energized voltage, or with a specifically designed tester supplied by the detector vendor.

(5) While testing circuits and/or equipment, the person performing the tests shall wear lineman's safety rubber gloves designed for the class of voltage in the circuits and/or equipment to be serviced and other protective equipment for this work.

e. Capacitors of any size and voltage class must be treated with special caution at all times. The ability of a capacitor to hold a potentially lethal charge for extremely long periods of time after it is de-energized makes it necessary to remove the capacitor from service in the following sequence.

(1) Isolate the capacitors by opening the breakers or isolation devices connecting them to the electrical system.

(2) Permit the capacitors to drain off the accumulated charge for five to ten minutes. (There is generally a built-in device which accomplishes this drain).

(3) Discharge and ground the capacitors. While performing these procedures, be very careful that sufficient distance is maintained from the capacitors with a "hot stick" in the event the drain-off device is not properly functioning.

(4) Vacuum circuit interrupters such as the types used in circuit breakers and load tap changers can generate lethal amounts of x-ray radiation.

f. Although the procedure for hipotting a vacuum circuit interrupter is similar to that used for any other electrical device, there are two areas that require the exercise of extra caution.

(1) During any hipotting operation, the main shield inside the interrupter can acquire an electrical charge that usually will be retained after the hipot voltage is removed. This shield is attached to the midband ring of the insulating envelope. A grounding stick should always be used to discharge the ring as well as the other metal parts of the assembly before touching the interrupter, connections, or breaker studs.

(2) High voltage applied across open gaps in a vacuum can produce hazardous x-radiation if the voltage across the contacts exceeds a certain level for a given contact gap. Therefore, do not make hipot tests on an open breaker at voltages higher than recommended by the manufacturer. During the hipot test, the steel front panel and partial side panels should be assembled to the breaker. Personnel should stand in front of the breaker to take advantage of the shielding afforded by the panels. If this position is not practical, equivalent protection can be provided by limiting personnel exposure to testing four three-phase

breakers per hour with the personnel not closer than 9 feet 10 inches to the interrupters. During equipment operation in the normal current carrying mode, there is no x-radiation because there are no open contacts.

(3) Refer to the equipment manufacturers' instruction manuals for proper testing methods and safety procedures.

g. Electrostatic coupling can be present in de-energized circuits at levels that may be fatal or cause involuntary reactions that may jeopardize personnel safety. When personnel are working on de-energized circuits that are adjacent to energized circuits, a flux linkage between circuits may occur if circuits are not properly grounded. Solid ground must be attached to the de-energized circuits at all times. De-energized equipment must always be grounded with an appropriate resistor grounding device before installing grounds and attempting to work on the equipment.

9-11. Electrical equipment fires

The standard procedure for fighting electrical fires is to open the circuit and then apply an approved extinguishing agent.

a. A carbon dioxide (CO_2) extinguisher offers the advantage of extinguishing the fire, cooling the apparatus, leaving no residue, and having no adverse affect on the insulation and metal parts, and it may be used on live circuits. Hence it is the preferred extinguishing agent for most electrical fires. However, when applied in confined spaces, such as in the engine room of a ship, the CO_2 should be purged with air before workmen are allowed to enter.

b. The dry-chemical extinguisher is satisfactory and may be used on live circuits. However, it leaves a residue and does not cool the apparatus so effectively as does the CO_2 extinguisher. A carbon tetrachloride extinguisher will put out the fire and cool the apparatus, but excessive use of this agent will be detrimental to the insulation and metal parts. Carbon tetrachloride is also very noxious and should be used only in well-ventilated places.

c. Water sprinklers and steam smothering apparatus may be used only after the circuit is de-energized. Such systems have been built into large machines and are very effective. The serious drawback to their extended usage is the time required to clean and dry the apparatus before it can be placed back in service.

d. Regardless of the type of extinguishing agent used, the apparatus should be thoroughly inspected and tested after the fire is out. The cause of the fire should be determined, and corrective action should be taken before the apparatus is put back in service. If no damage is apparent and an insulation-resistance test indicates normal, the apparatus may be started at reduced load and carefully observed as load is applied.

9-12. Equipment diagrams

To perform an effective maintenance program, it is necessary to have accurate data about the electrical power system. This may include one-line diagrams, short-circuit coordination studies, wiring and control diagrams, and other data that can be used as a reference point for future maintenance and testing. The purpose of these diagrams is to document and serve as an official record of equipment and circuit installation. NEMA has established standards for diagram symbols, device designations, and electrical symbols. The types of diagrams and drawings in common use are the following.

a. A process or flow diagram is a conceptual diagram of the functional inter-relationship of subsystems in pictorial form.

b. A one-line (single-line) diagram shows, by means of single lines and graphic symbols, the flow of electrical power or the course of electrical circuits and how they are connected. In this diagram, physical relationships are usually disregarded.

c. Schematic (elementary) diagrams show all circuits and device elements of the equipment. This diagram emphasizes the device elements and their functions, and it is always drawn with all devices shown in de-energized mode.

d. A control sequence (truth-table) diagram is a description of the contact positions or connections that are made for each position of control action or device.

e. A wiring diagram (connection diagram) locates and identifies electrical devices, terminals, and interconnecting wires in an assembly. This diagram may show interconnecting wiring by lines or terminal designations.

f. Interconnection diagrams show only the external connections between controllers and associated equipment or between various housing units of an assembly of switchgear apparatus.

g. Circuit layout and routing diagrams show the physical layout of the facility and equipment and how the circuit to the various equipment is run.

h. Electrical power system data, diagrams, and drawings are needed during maintenance and testing of electrical equipment. This may involve information and data relating to protective devices and relays. Such data are usually found in a short-circuit coordination study and usually encompass all the short-circuit values available in the power system, relays, and trip device settings. Normally, this study is performed as part of the initial facility design, and then validated during the construction phase to assure that equipment and values specified have been met. When accepting the facility, this study data should be used as a bench mark, and any changes that may have been made during construction in the system should be incorporated to update the study for future references.

i. System diagrams will generally be needed for large systems. Such diagrams may consist of control and monitoring system, lighting system, ventilation system, heating and air-conditioning system, emergency system, and other systems. All the system diagrams may interface with one another, such as electrical diagrams, fire and security diagrams, emergency power, and hydraulic pneumatic or mechanical systems. Each system may depend upon the integrity of each associated system within a facility. It is, therefore, important to understand how these systems interface and how they can be coordinated into a maintenance and test program.

9-13. Test forms

A key factor in an efficient maintenance and testing program is the preparation and filing of all inspection and test records. This enables mathematical trends to be established, and to a great extent future performance and maintenance measures can be predicted. Forms permit the orderly recording of data and are a reminder to record all pertinent factors, for example, temperature and relative humidity. A variety of forms are available in the industry or they can be tailored to fit requirements as needed.

a. One method of filing is by apparatus with the original inspection or test, and all successive tests for that apparatus would be filed in chronological order with the latest test on top. The important fact is that

records should be maintained (in whatever order or format that may be suitable) for comparison and evaluation.

b. Any efficient maintenance department should have forms available for their staff. A data file composed of consistent documentation is an integral part of any maintenance department. Test forms and procedures for specialty equipment are available from equipment manufacturers. It should be noted that forms can be generated to cover any set of unique circumstances that a qualified maintenance crew may encounter and that the attached forms are included only as samples and must not be regarded as the only specimen available.